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TOPSIS METHOD FOR MULTI-CRITERIA DECISION MAKING IN FUZZY ENVIRONMENT

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ABSTRACT

The TOPSIS (Technique for Order Performance by Similarity to Ideal Solution) method and its expansion were introduced five decades ago. During the recent years, the distinct techniques of multi-criteria decision-making (MCDM) have been used to develop decision makers to select better alternatives for various decision making problems. In this paper we represent the fuzzy set and TOPSIS according to the traditional decision theory with different algorithms. Using the algorithms ranking order of TOPSIS method, fuzzy TOPSIS method are calculated by closeness coefficients based on negative ideal solution (NIS) and proximity of positive ideal solution (PIS). Lastly, we present few applications of fuzzy TOPSIS method.

Key words: Fuzzy set; Multi-criteria decision-making; Triangular fuzzy number; TOPSIS; FTOPSIS.

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1. INTRODUCTION

Decision-making is a procedure now a day. Every decision makers can take their decision by the help of experts using set of alternatives and criteria. MCDM is a set of techniques to aid the decision makers to choose the acceptable alternatives with respect to the suitable criteria. The MCDM includes the set of alternatives, set of criteria. In the decision-making process, the decision makers provides the own evaluations for each alternatives with respect to the each criteria.

The Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) is one of the most widely used MCDM methods [1] in such solutions. The TOPSIS method was proposed by Hwang and Yoon in 1981 [2]. This TOPSIS method drudgery on the postulate of finding the excellent solution when compared to a perfect solution. In the business affairs we select technology; decisions are often taken in unpredictable environments and evaluations. The

evaluators may feel more assured in communicating the grading of alternatives for the maintain criteria in the interval-values[3].

The limitation of the TOPSIS method, it does not take care of distinct weights of NIS and PIS distances[4]-[5]. We extend this TOPSIS method to include where a decision maker may decide final ranking with more focus either on PIS or NIS. This is extending the final ranking step of TOPSIS method, which is calculated by closeness coefficient based on the separation from the NIS and contiguity to PIS. Also exemplify that the same focus on PIS as well as NIS distances. Our suggested ranking is equivalent to TOPSIS method.

In the following section 2, we discuss the basic definitions; main characteristics and basic concept of MCDM method with fundamental terminologies involving TOPSIS method. In Section 3, we discuss some parameter of the evaluation of Euclidean and distance value involving weights, the average linguistic performance with crisp data and the linguistic weights for ten scale criteria. The application of fuzzy TOPSIS method discussion in section 4 and Section 5, contains conclusion of research work with future scope.

2. PRELIMINARIES

Here, briefly we introduce some preliminary definitions, distance properties and concept, algorithm of TOPSIS method including comparisons of ranking order.

Definition 1. Let U be an Universe of discourse with an element $x \in U$. A fuzzy set $\tilde{X}$ in U is characterized by $\mu_{\tilde{X}}(x),\ x \in [0,1]$ and x in $\tilde{X}$ as

$$\tilde{X} = \{(x, \mu_{\tilde{X}}(x)) : x \in U\},\ \text{where } \mu_{\tilde{X}}(x) : U \rightarrow [0,1]$$

Definition 2. Let $\tilde{x} = [x_1 \quad \mathrm{x}_2 \quad \mathrm{x}_3]$ be a triangular fuzzy number (TNF), then the membership function is given by

$$\mu_{\tilde{X}}(x) = \begin{cases} 0 & \text{if } x < x_1 \\ \dfrac{\mathrm{x} - x_1}{x_2 - x_1} & \text{if } x_1 \le x \le x_2 \\ \dfrac{x_3 - x}{x_3 - x_2} & \text{if } x_2 \le x \le x_3 \\ 0 & \text{if } x > x_3 \end{cases}$$

where $x_1 < x_2 < x_3$.

Definition 3. Let $\tilde{p} = (p_1, p_2, p_3)$ and $\tilde{q} = (q_1, q_2, q_3)$ are two positive TFNs, then the operation with these fuzzy numbers as follows

$$\tilde{p}(+)\tilde{q} = (p_1(+)q_1, p_2(+)q_2, p_3(+)q_3)$$
$$\tilde{p}(-)\tilde{q} = (p_1(-)q_1, p_2(-)q_2, p_3(-)q_3)$$
$$\tilde{p}(\times)\tilde{q} = (p_1(\times)q_1, p_2(\times)q_2, p_3(\times)q_3)$$
$$\tilde{p}(/)\tilde{q} = (p_1(/)q_1, p_2(/)q_2, p_3(/)q_3)$$
$$k\tilde{p} = (kp_1, kp_2, kp_3)$$

Definition 4. Let $\tilde{x} = (x_1, x_2, x_3)$ and $\tilde{y} = (y_1, y_2, y_3)$ are two TFNs. Then the distance measure among $\tilde{x}$ and $\tilde{y}$ is given by

$$d(\tilde{x}, \tilde{y}) = \sqrt{\frac{1}{3}\sum_{i=1}^{3}(x_i - y_i)^2}$$

2.1. Properties of Distance

Property-1 Let $\tilde{X}$ and $\tilde{Y}$ are two real no., then $d(\tilde{X}, \tilde{Y})$ is identical.

Proof: Let $\tilde{X}$ and $\tilde{Y}$ are two real numbers. Then suppose $x = x_1 = x_2 = x_n$ and $y = y_1 = y_2 = y_n$

So $$d(\tilde{X}, \tilde{Y}) = \frac{1}{2}\{\max(|x_1 - y_1|, |x_2 - y_2|) + |x_n - y_n|\}$$

$$= \frac{1}{2}\{\max(|x - y|, |x - y|) + |x - y|\}$$

$$= \frac{1}{2}\{|x - y| + |x - y|\} = |x - y|$$

Property-2 Two triangular fuzzy numbers $\tilde{X}$ and $\tilde{Y}$ are identical if and only if $d(\tilde{X}, \tilde{Y}) = 0$.

Proof. Suppose $\tilde{X} = (x_1, x_n, x_2)$ and $\tilde{Y} = (y_1, y_n, y_2)$ be two triangular fuzzy numbers. If $\tilde{X}$ and $\tilde{Y}$ are identical, then $x_1 = y_1$, $x_2 = y_2$ and $x_n = y_n$. So

$$d(\tilde{X}, \tilde{Y}) = \frac{1}{2}\{\max(|x_1 - y_1|, |x_2 - y_2|) + |x_n - y_n|\}$$

$$= \frac{1}{2}\{\max(0,0) + 0\} = 0$$

If $d(\tilde{X}, \tilde{Y}) = 0$, then $\frac{1}{2}\{\max(|x_1 - y_1|, |x_2 - y_2|) + |x_n - y_n|\} = 0$

i.e. $\{\max(|x_1 - y_1|, |x_2 - y_2|) + |x_n - y_n|\} = 0$

Hence $\max(|x_1 - y_1|, |x_2 - y_2|) = 0$ and $|x_n - y_n| = 0$

$|x_1 - y_1| = 0$, $|x_2 - y_2| = 0$ and $|x_n - y_n| = 0$

So $\tilde{X}$ and $\tilde{Y}$ are identical.

2.2. TOPSIS Method

TOPSIS method is more extensively used method in MCDM methods[5]-[6]. It was suggested by Hwang and Yoon[2] and extended by Yoon[7]. In TOPSIS method, the most alternative is the one nearest to the PIS and farthest from the NIS. The PIS is maximum the benefit-criteria and minimum the cost-criteria. Similarly, the NIS maximum the cost-criteria and minimum the

benefit-criteria. The alternative which has the least Euclidean-distance from PIS while being farthest from NIS [8].

Suppose, the decision matrix $M_d = [m_{\delta\theta}]_{pq}$, where $\delta = 1,2,\cdots,p;\ \theta = 1,2,\cdots,q$ and $m_{\delta\theta}$ is the performance rating of the alternative $A = [a_\delta|\delta = 1,2,\cdots,p]$ a set of alternatives, $C = [c_\theta|\theta = 1,2,\cdots,q]$ a set of criteria and $W = [w_\theta|\theta = 1,2,\cdots,q], w_\theta > 0, \sum_{\theta=1}^{q} w_\theta = 1$.

Algorithm-1

Step 1. Construct the decision matrix (M_d) as:

$$M_d = [m_{\delta\theta}]_{pq} \text{ , where } \delta = 1,2,\cdots,p;\ \theta = 1,2,\cdots,q$$

Step 2. Compute the normalized decision matrix $(N_{\delta\theta})$ as:

$$N_{\delta\theta} = \frac{m_{\delta\theta}}{\sqrt{\sum_{\delta=1}^{p} m_{\delta\theta}^2}} ,\delta = 1,2,\cdots,p;\ \theta = 1,2,\cdots,q$$

Step 3. Compute the weighted normalized decision matrix $(t_{\delta\theta})$ as:

$$t_{\delta\theta} = w_\theta \times N_{\delta\theta} ,\delta = 1,2,\cdots,p;\ \theta = 1,2,\cdots,q$$

Step 4. Calculate PIS, and NIS as:

$$Positive\ ideal\ solution = \{t_1^+, t_2^+, \cdots, t_\theta^+\}, where\ t_\theta^+ = \begin{cases} max(t_{\delta\theta}|\delta = 1,2,\cdots,p), if\ \theta \epsilon B \\ min(t_{\delta\theta}|\delta = 1,2,\cdots,p)\ if\ \theta \epsilon C \end{cases}$$

$$Negative\ ideal\ solution = \{t_1^-, t_2^-, \cdots, t_\theta^-\}, where\ t_\theta^- = \begin{cases} min(t_{\delta\theta}|\delta = 1,2,\cdots,p), if\ \theta \epsilon B \\ max(t_{\delta\theta}|\delta = 1,2,\cdots,p)\ if\ \theta \epsilon C \end{cases}$$

Step 5. Compute the distance of each alternative p in relation to the ideal solution as:

$$DIS_\delta^+ = \sqrt{\sum_{\theta=1}^{q} \left(t_{\delta\theta} - t_\theta^+\right)^2} ,\delta = 1,2,\cdots,p$$

$$DIS_\delta^- = \sqrt{\sum_{\theta=1}^{q} \left(t_{\delta\theta} - t_\theta^-\right)^2} ,\delta = 1,2,\cdots,p$$

Step 6. Compute the closeness coefficient of the alternatives as:

$$CLCO_\delta = \frac{DIS_\delta^-}{DIS_\delta^+ + DIS_\delta^-}$$

2.3. Comparison of Ranking: TOPSIS

	Case 1	**Case 2**	**Case 3**	**Case 4**
$DIS_2^+ - DIS_1^+$	> 0	< 0	< 0	> 0
$DIS_2^- - DIS_1^-$	> 0	< 0	> 0	< 0
Decision	Not-yet ?	Not-yet ?	No-doubt $RC_1 < RC_2$	No-doubt $RC_2 < RC_1$

In the ranking index, the relative significance of separations DIS_δ^+ and DIS_δ^- are not considered [4]. The main TOPSIS simply sums DIS_δ^+ and DIS_δ^- without utilize any parameter that respective consequence of these two separations. Now we analyzed the index of the respective consequence to the perfect solution and pointed out a_1 is assume to be the alternative with$DIS_1^- = DIS_1^+$, and all alternatives a_2 with $DIS_2^- > DIS_2^+ > DIS_1^+$ are ranked proceeding to a_1. So a_1 is closer than a_2 to the positive ideal solution [4]. It is true but not surprising because a_1 is also closer than a_2 to the negative ideal solution.

The closeness coefficient ranking orders of a_1 and a_2 be decided by using the relative information of closeness coefficient of separation measures defined by Step 5. By using the information of $DIS_2^+ - DIS_1^+$ and $DIS_2^- - DIS_1^-$, we can analyze the possible results of the ranking order of alternatives a_1 and a_2 as shown in Table 1.

Proposition 1. In the TOPSIS method, the sufficient condition of $CLCO_2^+ < CLCO_1^+$ is $DIS_2^- \cdot DIS_1^+ < DIS_1^- \cdot DIS_2^+$.

Proof: Let $DIS_2^- \cdot DIS_1^+ < DIS_1^- \cdot DIS_2^+$

$$\Rightarrow DIS_2^- \cdot DIS_1^+ + DIS_2^- \cdot DIS_1^- < DIS_1^- \cdot DIS_2^+ + DIS_2^- \cdot DIS_1^-$$

$$\Rightarrow DIS_2^-\left(DIS_1^+ + DIS_1^-\right) < DIS_1^-\left(DIS_2^+ + DIS_2^-\right)$$

$$\Rightarrow \frac{DIS_2^-}{DIS_2^+ + DIS_2^-} < \frac{DIS_1^-}{DIS_1^+ + DIS_1^-} \Rightarrow CLCO_2^+ < CLCO_1^+.$$

Proposition 2. The sufficient condition of TOPSIS method, $CLCO_1^+ \le CLCO_2^+$ is

$$DIS_1^- \cdot DIS_2^+ \le DIS_2^- \cdot DIS_1^+.$$

Proof. Let $DIS_1^- \cdot DIS_2^+ \le DIS_2^- \cdot DIS_1^+$

$$\Rightarrow DIS_1^- \cdot DIS_2^+ + DIS_1^- \cdot DIS_2^- \le DIS_2^- \cdot DIS_1^+ + DIS_1^- \cdot DIS_2^-$$

$$\Rightarrow DIS_1^-\left(DIS_2^+ + DIS_2^-\right) \le DIS_2^-\left(DIS_1^+ + DIS_1^-\right)$$

$$\Rightarrow \frac{DIS_1^-}{DIS_1^+ + DIS_1^-} \le \frac{DIS_2^-}{DIS_2^+ + DIS_2^-}$$

$$\Rightarrow CLCO_1^+ \le CLCO_2^+.$$

This consequence is identical to the main TOPSIS showing in proposition-1. The ranking index of the main TOPSIS has comparative significance of two separations.

2.4. Formulation of FMCDM problem

A MCDM having $p\ alternatives$ with $q\ criteria$ can be expressed as a $decision\ matrix$

$$\tilde{M}_d = \begin{bmatrix} m_{11} & m_{12} & \cdots & m_{1q} \\ m_{21} & m_{22} & \cdots & m_{2q} \\ \vdots & \vdots & \ddots & \vdots \\ m_{p1} & m_{p2} & \cdots & m_{pq} \end{bmatrix}$$

where $m_{\delta\theta}$ is a numeral value which describe the value of the $\delta^{th}\ alternative$ with $\theta^{th}\ criterion$. The consequence of $criterion\ C_\theta$ to the $decision\ t_\theta$. Let t be the vector $t = \left[t_1, t_2, \cdots, t_q\right]$. Basically, all weights are determined by a single decision maker or through the group of experts.

Remark 2.4.1 The FMCDM allocate the significance degree of criteria can used a practical procedure described [9], where a identical among the significance of an attribute and a TFN is described.

Table 1 Linguistic terms for triangular fuzzy numbers (TFN)

Attribute Grade	Linguistic terms	TFN
01	Very worst	(0.00, 0.00, 0.05)
02	Low worst	(0.0,0 0.05, 0.15)
03	Medium worst	(0.05, 0.15, 0.25)
04	Worst	(0.15, 0.25, 0.35)
05	Low good	(0.25, 0.35, 0.45)
06	Medium good	(0.35, 0.45, 0.55)
07	Good	(0.45, 0.55, 0.65)
08	Very good	(0.55, 0.65, 0.75)
09	Less excellent	(0.65, 0.75, 0.85)
10	Excellent	(0.75, 0.85, 0.95)
11	Outstanding	(0.95, 1.00, 1.00)

3. FUZZY TOPSIS

The Chen [10] extended TOPSIS method with triangular fuzzy numbers (TFN). Chen [10] also introduced a vertex technique to determine the distance among two TFNs $\tilde{x} = (x_1, x_2, x_3)$ and $\tilde{y} = (y_1, y_2, y_3)$. For the distance measure among $\tilde{x}$ and $\tilde{y}$ is given by

$$d(\tilde{x}, \tilde{y}) = \sqrt{\frac{1}{3}\sum_{i=1}^{3}(x_i - y_i)^2}$$

Algorithm-2

Step 1. Construct the fuzzy decision matrix (FDM) $\tilde{M}_d$. In FDM each $\tilde{m}_{\delta\theta}$ is a TFN $\tilde{m}_{\delta\theta} = (m_{\delta\theta}, x_{\delta\theta}, y_{\delta\theta})$.

Step 2. Construct the normalized FDM $\tilde{N}_{\delta\theta}$.

For each fuzzy number $\tilde{m}_{\delta\theta} = (m_{\delta\theta}, x_{\delta\theta}, y_{\delta\theta})$, we construct the set of $\alpha - cut$ as $\tilde{m}_{\delta\theta} = \left([\tilde{m}_{\delta\theta}]_\alpha^L,\ [\tilde{m}_{\delta\theta}]_\alpha^U \right)$, $\alpha \in [0,1]$. Each fuzzy number $\tilde{m}_{\delta\theta}$ is transformed into an interval. Now this interval is transformed into normalised interval

$$[\tilde{n}_{\delta\theta}]_\alpha^L = [\tilde{m}_{\delta\theta}]_\alpha^L \Big/ \sum_{\delta=1}^{m} \left\{ \left([\tilde{m}_{\delta\theta}]_\alpha^L\right)^2 + \left([\tilde{m}_{\delta\theta}]_\alpha^U\right)^2 \right\} \quad \theta = 1,2,...,n.$$

and $$[\tilde{n}_{\delta\theta}]_\alpha^U = [\tilde{m}_{\delta\theta}]_\alpha^U \Big/ \sum_{\delta=1}^{m} \left\{ \left([\tilde{m}_{\delta\theta}]_\alpha^L\right)^2 + \left([\tilde{m}_{\delta\theta}]_\alpha^U\right)^2 \right\} \quad \theta = 1,2,...,n.$$

Now $\left([\tilde{n}_{\delta\theta}]_\alpha^L, [\tilde{n}_{\delta\theta}]_\alpha^U\right)$ is a normalized interval of $\left([\tilde{x}_{ij}]_\alpha^L, [\tilde{x}_{ij}]_\alpha^U\right)$ which is transformed into a fuzzy number $\tilde{N}_{\delta\theta} = (n_{\delta\theta}, a_{\delta\theta}, b_{\delta\theta})$. According to remark by setting $\alpha = 1$, we have $[\tilde{n}_{\delta\theta}]_{\alpha=1}^L = [\tilde{n}_{\delta\theta}]_{\alpha=1}^U = n_{\delta\theta}$ and by setting $\alpha = 0$, we have $[\tilde{n}_{\delta\theta}]_{\alpha=1}^L = n_{\delta\theta} - a_{\delta\theta}$ and $[\tilde{n}_{\delta\theta}]_{\alpha=1}^U = n_{\delta\theta} + b_{\delta\theta}$, then $a_{\delta\theta} = n_{\delta\theta} - [\tilde{n}_{\delta\theta}]_{\alpha=0}^L$ and $b_{\delta\theta} = [\tilde{n}_{\delta\theta}]_{\alpha=0}^U - n_{\delta\theta}$. Now $\tilde{N}_{\delta\theta} = (n_{\delta\theta}, a_{\delta\theta}, b_{\delta\theta})$ is the fuzzy number of the normalized interval $\left([\tilde{n}_{\delta\theta}]_\alpha^L, [\tilde{n}_{\delta\theta}]_\alpha\right)$. This $\tilde{N}_{\delta\theta}$ is a normalized positive triangular fuzzy number.

Step 3. Let the distinct significance of each criterion, we can construct the weighted normalized FDM as $t_{\delta\theta} = \tilde{N}_{\delta\theta}.\tilde{w}_\theta$ where $\tilde{w}_\theta$ is the weight of the θ^{th} criterion.

Step 4. So we identify the positive ideal solution $PIS = \widetilde{A}^{+} = \left(t_1^{+}, t_2^{+}, ..., t_q^{+}\right)$ and the negative ideal solution $NIS = \widetilde{A}^{-} = \left(t_1^{-}, t_2^{-}, ..., t_q^{-}\right)$ where each $t_\theta^{+} = (1,1,1)$ and $\widetilde{v}_\theta^{-} = (0,0,0)$, $\theta = 1,2,...,q$ for each criteria.

Step 5. Using the distance definition we calculate the distance of each alternative from the PIS and NIS as $DIS_i^{+} = \sum_{\theta=1}^{q} d\left(t_{\delta\theta}, t_\theta^{+}\right)$ and $DIS_\theta^{-} = \sum_{\theta=1}^{q} d\left(t_{\delta\theta}, t_\theta^{-}\right)$, $\delta = 1,2,..., p$ respectively.

Step 6. A relative closeness is defined as: $CLCO_\delta = \dfrac{DIS_\delta^{-}}{\left(DIS_\delta^{+} + DIS_\delta^{-}\right)}$, $\delta = 1,2,3,..., p.$

4. FEW APPLICATIONS

First we identify that there are excellent observations regarding FMCDM applications [5], [11]-[12].

4.1. Location Problem (LP)

In a FTOPSIS approaches for selecting plant location is proposed [13]. The grading of alternatives and the weights of criteria are estimated in linguistic terms by TFS. In [14] FTOPSIS technique is used for logistic company excited in executing a new urban distribution centre involving three alternatives (A_1, A_2, A_3). Firstly, form a committee including three decision makers. The criteria are accessibility(C_1), security(C_2), connectivity to multimodal transport(C_3), costs(C_4), environmental impact(C_5), proximity to customers(C_6), proximity to suppliers(C_7), resource availability(C_8), conformance to sustainable freight regulations(C_9), possibility of expansion(C_{10}), quality of service(C_{11}). Same type of problems are considered by different authors[15].

4.2. Supplier-Selection (SS)

In paper [16] introduced a FTOPSIS approach based on trapezoidal fuzzy numbers for solving the supplier-selection problem. Five benefit criteria are selected as desirability of supplier; affinity closeness; scientific capability; conformality quality; and combat resolution.

4.3. Renewable Energy (RE)

A FTOPSIS method is used in [17], for ranking the renewable energy supply structure in Turkey. There are five criteria with positive impact, advantage of CO_2 emission, job creation, efficiency, installed capacity, amount of energy produced and four criteria with negative impact, investment cost, operation and maintenance cost, payback period, land use.

4.4. Reverse Logistics (RL)

A FTOPSIS technique applied in [18], for ranking of solutions for reverse logistic (RL) implementation into business process due to increasing the environmental awareness. There are eight sub-criteria, calculated fuzzy aggregated decision matrix of sub-criteria i.e. MB, OB, PB, LB, TB, IB, FB, and ISB. Finally, take the global ranking of RL barriers for the different criterion, say, management barriers; organizational barriers; product barriers; legal barriers; technological barriers; infrastructural barriers; financial barriers; involvement and support barriers.

5. CONCLUSION

The FTOPSIS method is a very popular method for solving the decision making problems. In this paper, we presented about the TOPSIS and FTOPSIS methods. The ranking index of these

methods is irrespective of the weights of separations of alternatives from PIS and NIS. A new ranking index was proposed and two propositions were provided. Finally we have presented several works that presents some applications of fuzzy TOPSIS such as, location problems; supplier selection; renewable energy and reverse logistics. In this survey, future research in this line of investigation is still required.

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